Fotónica de plasmones superficiales en nanostructuras metálicas

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INSTITUTO DE ESTRUCTURA DE LA MATERIA

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&

Fotonica de Plasmones Superficiales

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RESUMEN

- Introducción:

  - PLASMONES SUPERFICIALES

  - NANOESTRUCTURAS

- Motivación/Avances recientes

- Líneas de Trabajo

- Actividad Presente/Futura

RESUMEN

- **Introducción**:

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INTRODUCCIÓN

ELECTROMAGNETISMO/MATERIA CONDENSADA:

INTERACCIÓN RADIACIÓN-MATERIA

- Visible e IR, THz
- Metales, Semiconductores: Micro/Nano-Estructuras

TEORÍA:

- Ecuaciones de Maxwell: *Scattering* (Dispersión)+ Dispersión Temporal, Propagación
- Modelos semiclásicos: Emisión espontánea

PLASMONS

- Drude's Theory of Metals: Free-electron Model

$$\boxed{\epsilon(\omega) = 1 - \frac{\omega_p^2}{\omega(\omega + \imath\gamma)}}, \omega_p \equiv \text{plasma frequency}$$

- $\omega < \omega_p$, Opaque; $\omega > \omega_p$, Transparent

PLASMONS

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- $\omega = \omega_p$, Charge-density oscillations:

  PLASMONS (bulk)

PLASMONS

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- $\omega = \omega_p$, Charge-density oscillations:

  PLASMONS (bulk)

  $\Downarrow$

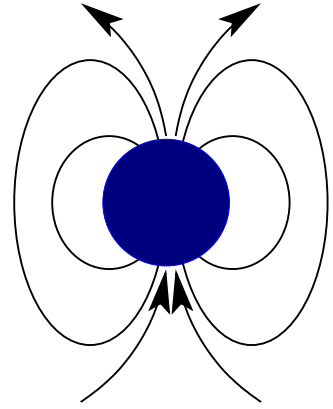
  METAL BOUNDARIES? PARTICLES, SURFACES

SURFACE PLASMONS

MIE SCATTERING (SPHERE, CYLINDER)

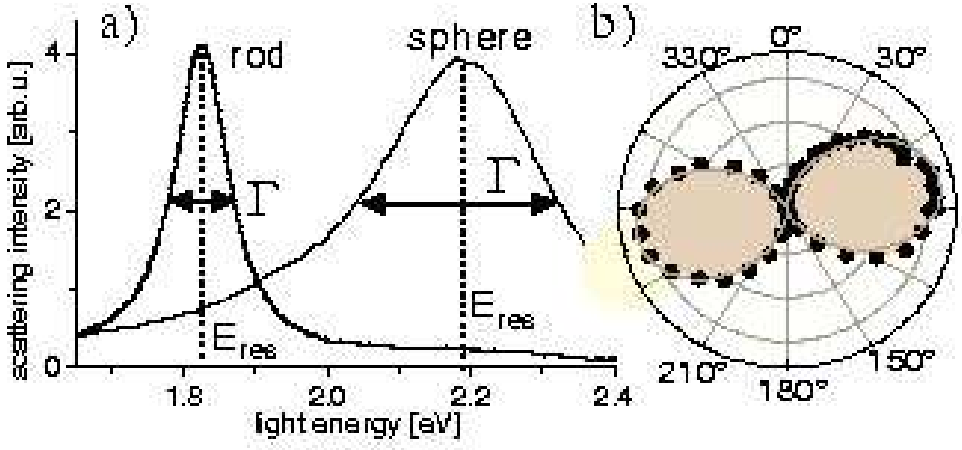
Nanoparticle: Lowest (Dipole) order,

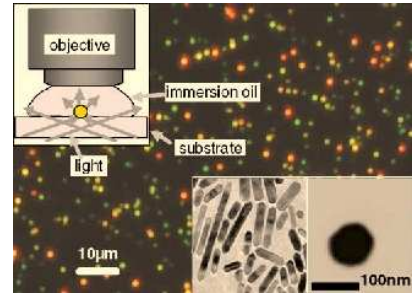
$$p \propto \alpha E, \quad \boxed{\alpha = a^3 \frac{\epsilon(\omega)-1}{\epsilon(\omega)+2}}$$



$$\epsilon(\omega) = -2, (\omega = \omega_p/3^{1/2})$$

PARTICLE/RESONANT SP



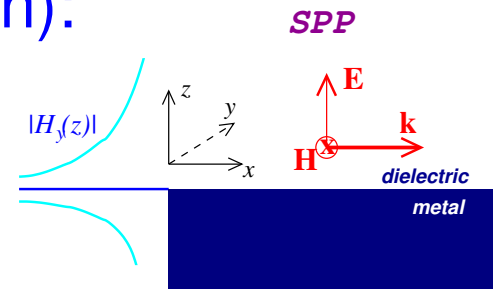


Sonnichsen et al, PRL (2002)

SP Polaritons

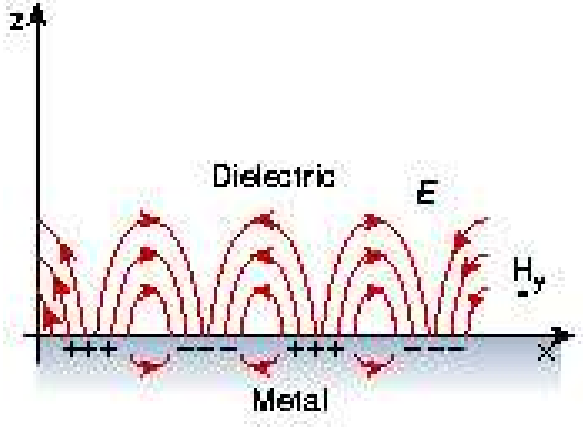
Electromagnetic Wave (TM—p polarization):

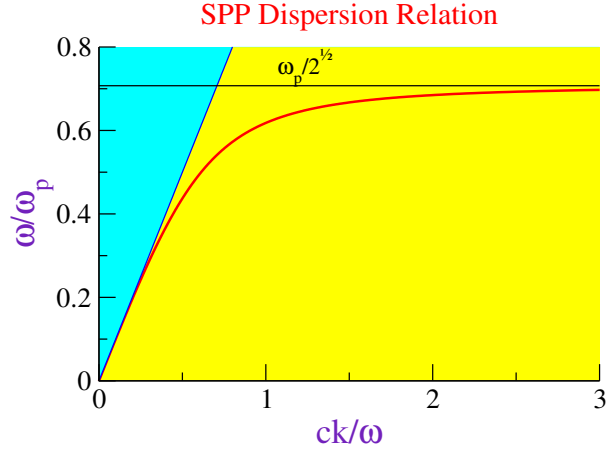
$$H_y(x,z,t) \propto e^{-\beta_0(\omega)z} \exp[i(k(\omega)x - \omega t)],\ z > 0,$$

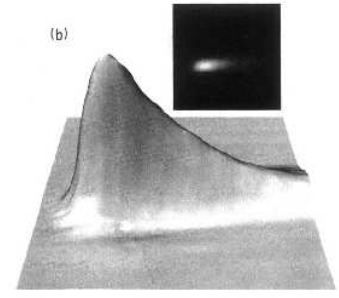


DISPERSION RELATION

$$k(\omega) = \frac{\omega}{c}\left(\frac{\epsilon_d \epsilon(\omega)}{\epsilon(\omega)+\epsilon_d}\right)^{1/2}$$







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- **Motivación/Avances recientes**

- Líneas de Trabajo:

  - Control: Micro/Nano-Óptica

  - Intensificación: SERS & Óptica No-Lineal

- Actividad Presente/Futura

Surface Plasmon Photonics

CSIC

SP Polaritons

- Propagation length, Evanescent ($\perp$ confinement)

  $\Rightarrow$ 2D EM WAVES

- Scattering by sub-wavelength (nano/micro) structures

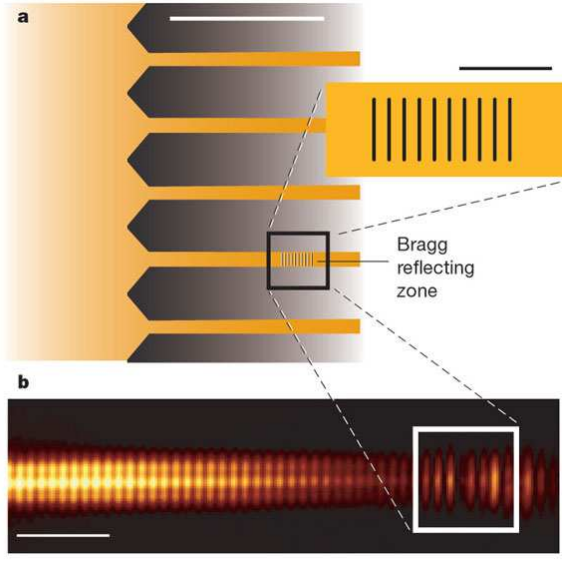
SP resonances: Metal nano-structures, nano-particles

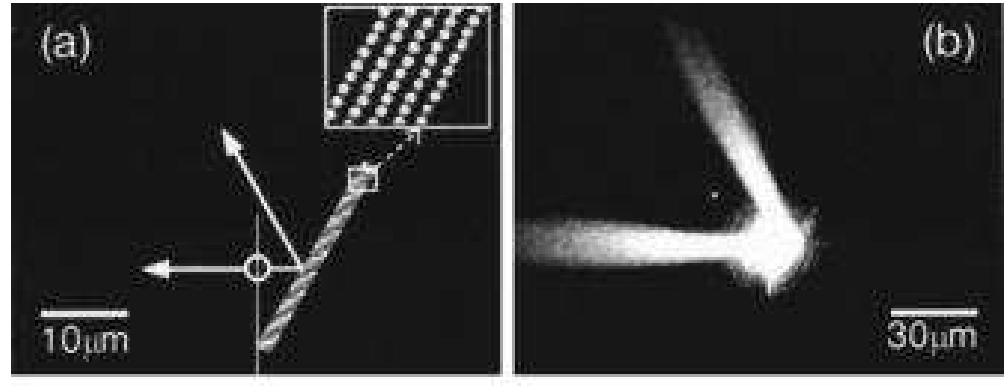
- Large EM Fields: enhancing Excitation
- Large local EM density of states: driving Emission

SP Photonics: Defects

SPP Micro/Nano-Optics

Nanodefects, Arrays

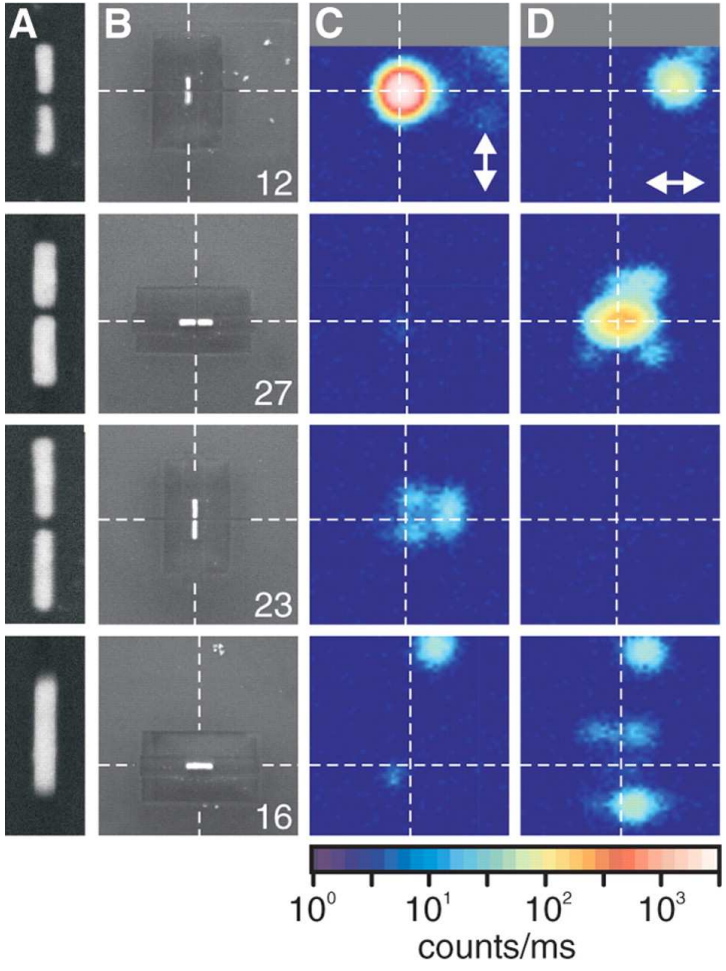


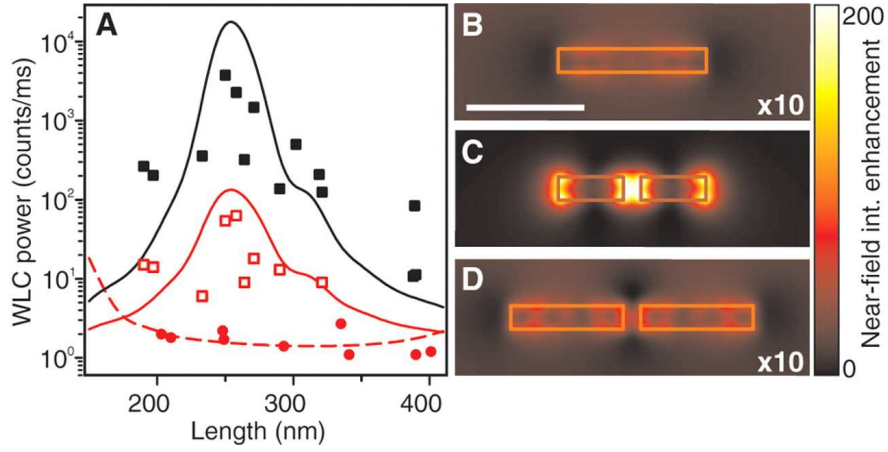


Barnes et al, Nature (2003)

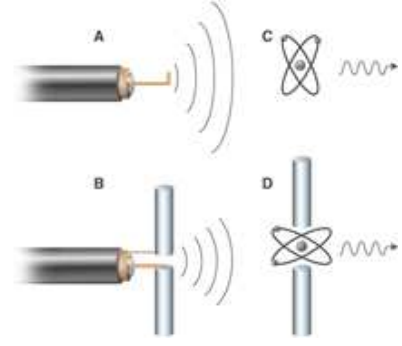
Ditlbacher et al, APL (2002)

SP resonances: Nano-antennas





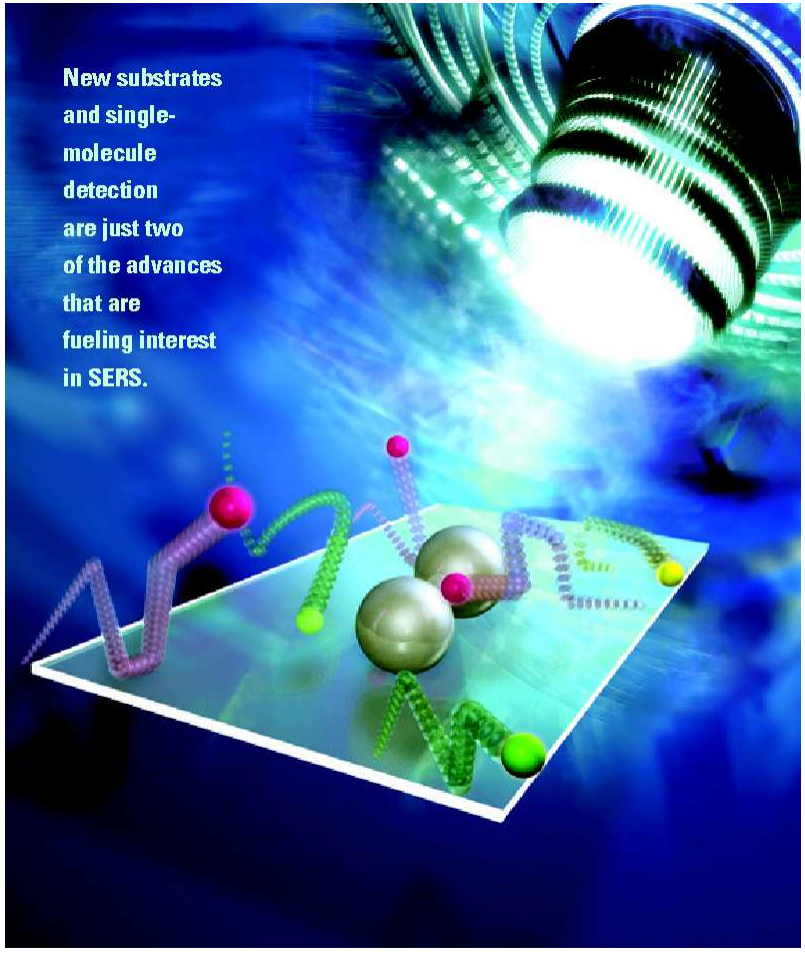
Radio and optical antennas



Mühschlegel *et al*, Science 2005

Greffet, Science 2005

SERS



New SERS Substrates

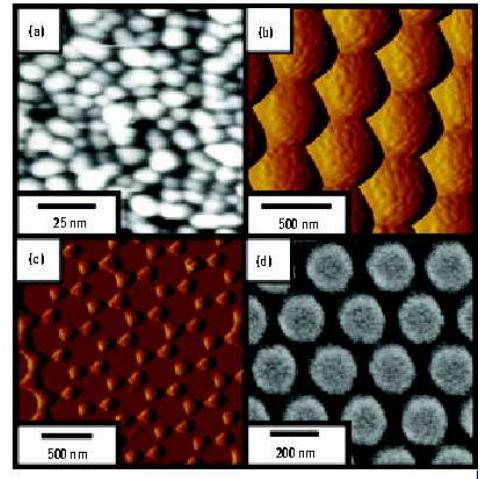
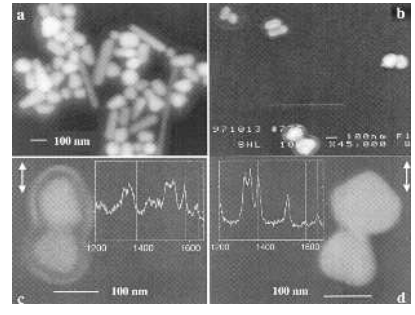


FIGURE 2. Sample substrates.

(a) Metal island film, (b) metal film over nanospheres, (c) triangular nanoparticle array fabricated with nanosphere lithography, and (d) cylindrical nanoparticle array fabricated with electron-beam lithography.

SERS Single Molecule Detection



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- **Líneas de Trabajo**:

  - Control: Micro/Nano-Óptica

  - Intensificación: Emisión espontánea (Fluorescencia, SERS, etc)

- Actividad Presente/Futura

CSIC

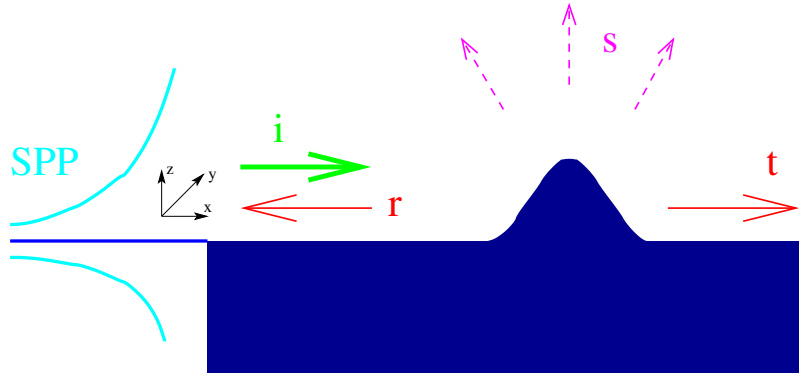
CONTROLLING SPP

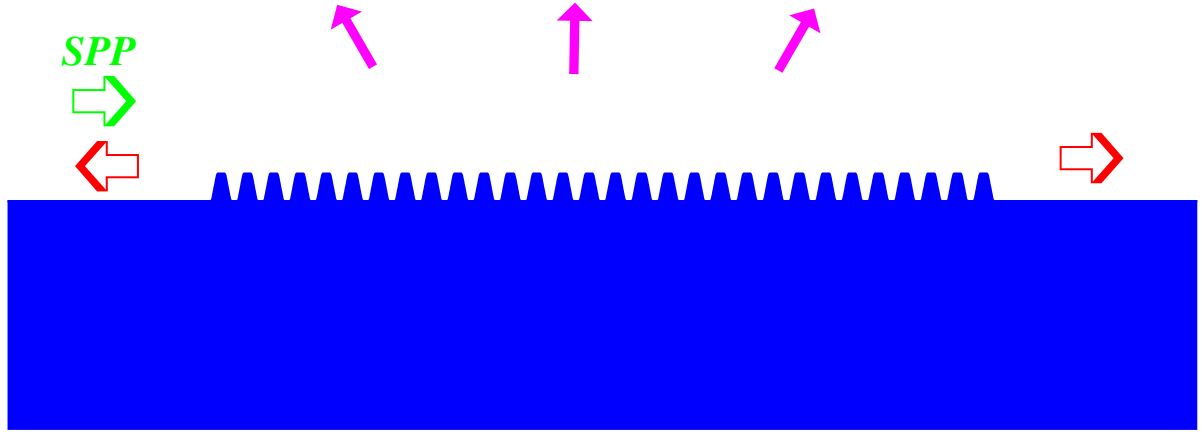
$\Downarrow$

Micro/Nano-Optics

SPP Scattering by sub-wavelength defects

SPP Scattering by defects (single, array)



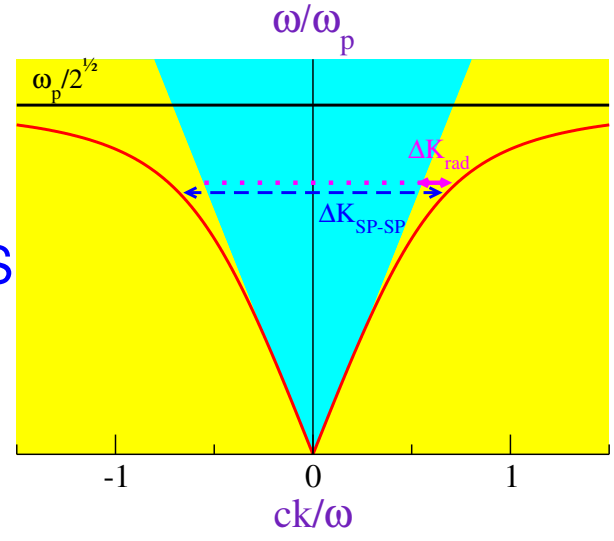


Roughness-induced SPP Scattering

- SPP-Light Coupling $\Longleftrightarrow$ Radiative Leakage

$$\Delta K^{\pm} = |k(\omega) \mp (\omega/c)\sin\theta|$$

GRATINGS (diffraction) & DEFECTS



- SPP-SPP $\Delta K = 2k(\omega)$

SUB-WAVELENGTH DEFECT

- SPP band gaps Bragg scattering/Defect Arrays
- SPP Resonances

Single (wider/deeper) DEFECTS,

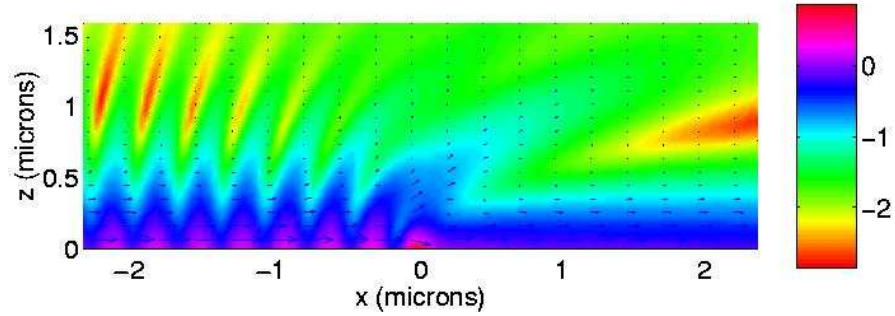
ARRAYS (localized states within SPP band gaps)

SPP Scattering by 1D surface defects

SPP MIRRORS

(Nano)Groove/Ridge

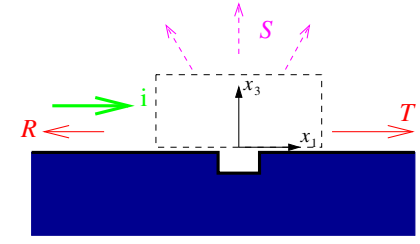
(λ =630 nm, $a = h/2 = 63$ nm)

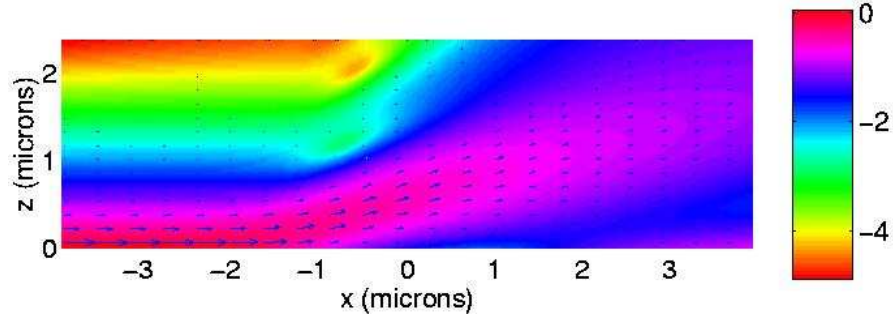


SPP-LIGHT EMITTERS

Groove/Ridge

(λ =630 nm, $a = 10h = 1.26\,\mu$m)

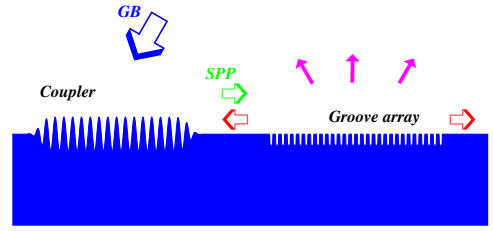




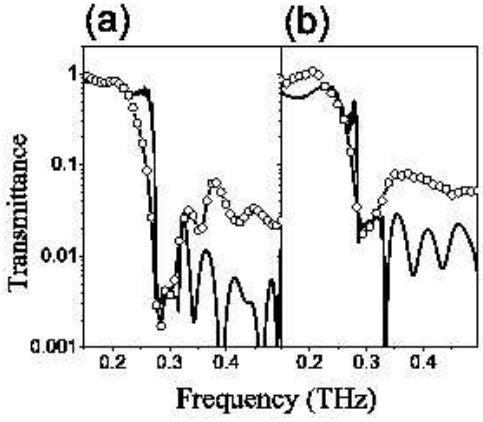
Sánchez-Gil & Maradudin, APL 98, PRB 99

SPP Scattering by 1D defect arrays

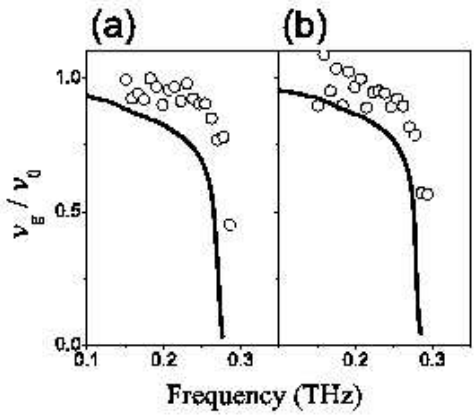
THz SPP: Groove array



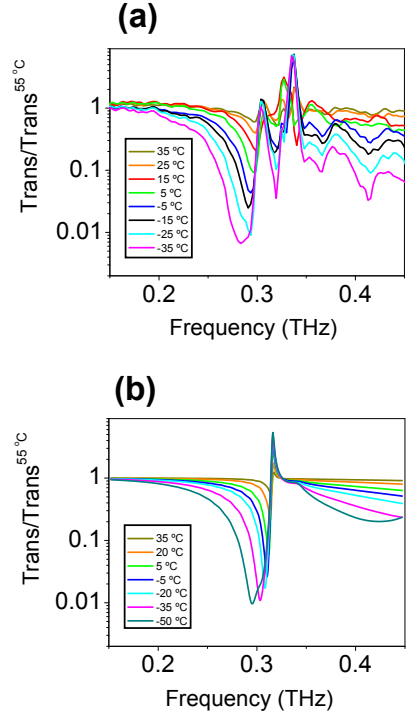
SPP band gaps



Slow SPP



Thermal switching



Gómez Rivas, Kuttge, Haring, Kurz, Sánchez-Gil, PRL 04, PRB 06 & APL

CSIC

SP RESONANCES: ENHANCED LOCAL EM FIELDS

$\Downarrow$

Spontaneous emission:

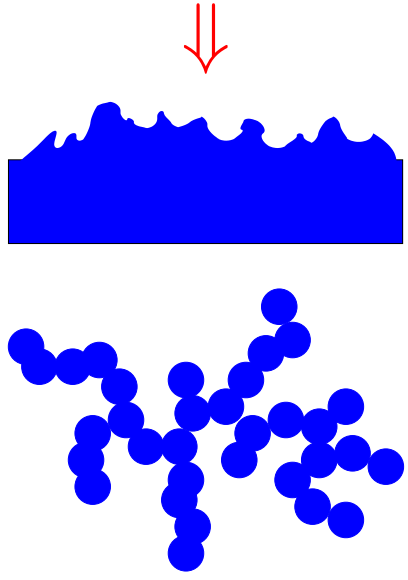
Surface-enhanced Raman, Fluorescence, ...

Light Scattering by Nanostructured Metals

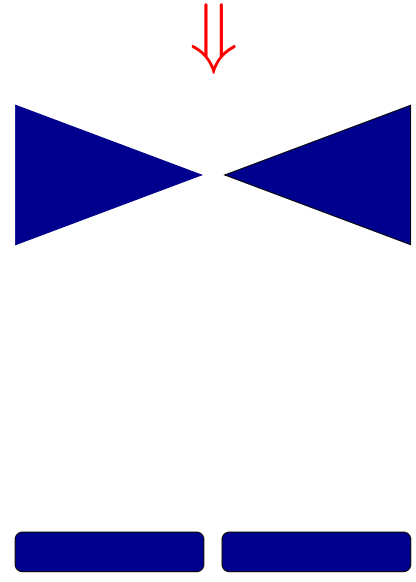
SP: EM Field Enhancement

LIGHT SCATTERING

Nanostructured surfaces/aggregates

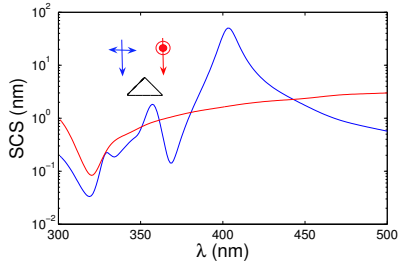


Nanoparticle (nanoantennas)

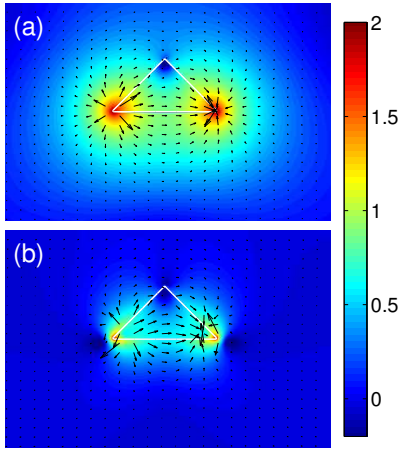


Nanowires: SP resonance

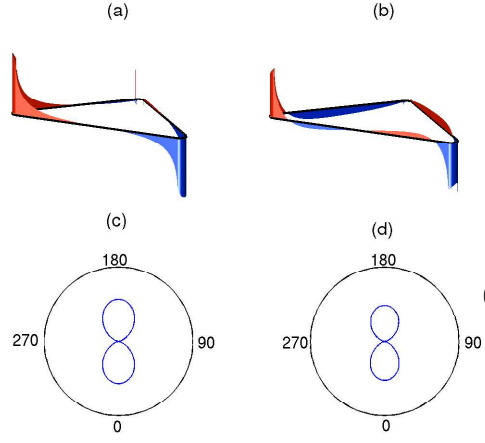
Nano-triangles



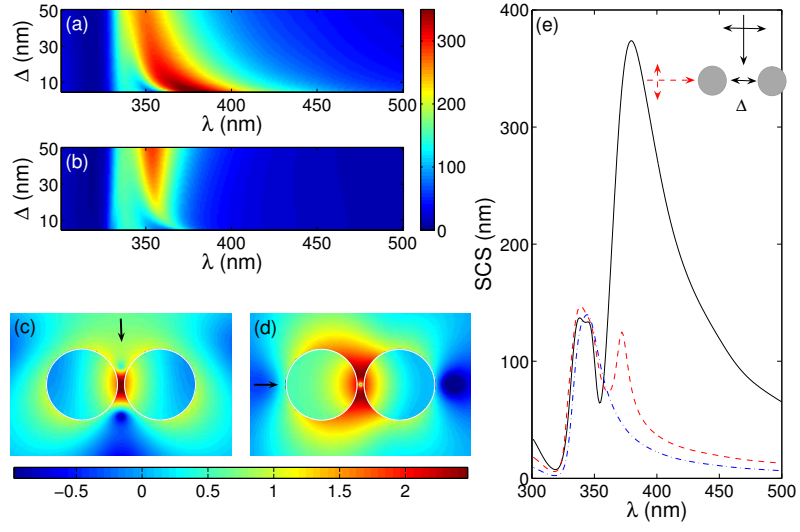
SPR: Near Field



Surface Charge

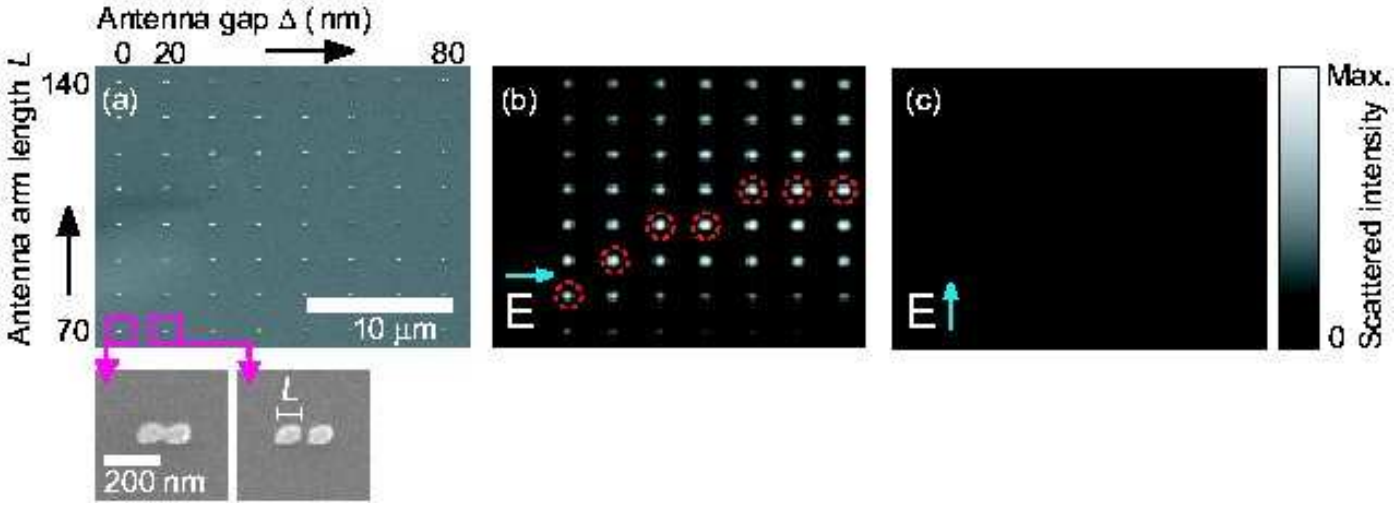


Nano-dimers

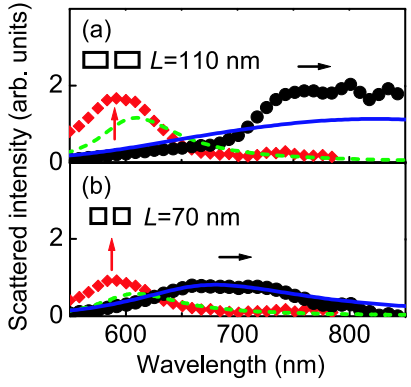


Giannini et al, preprint (JOSAA)

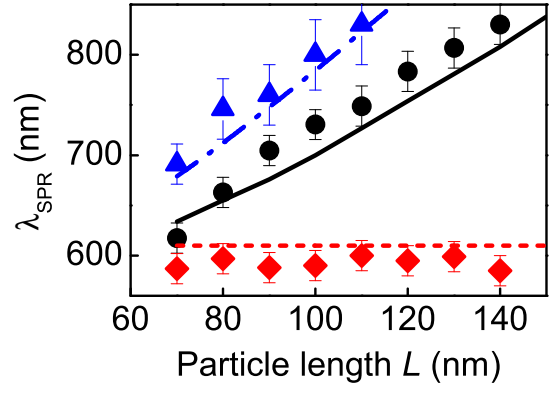
Nanoantenna: SP resonance



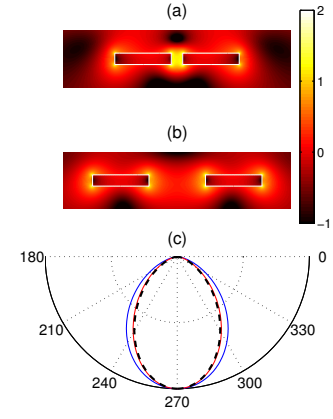
Scattering Cross Section



SP resonance



Near Field



Muskens, Gomez Rivas, Giannini, Sanchez-Gil, preprint (PRB)

ACTIVIDAD PRESENTE/FUTURA

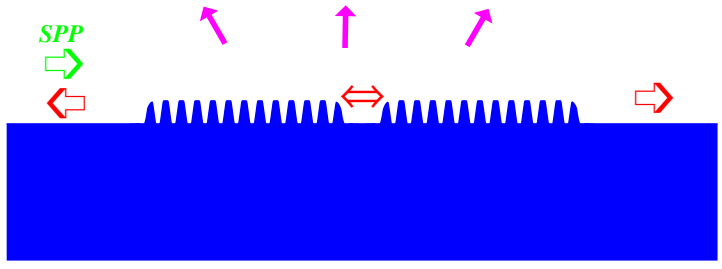
Fotónica de Plasmones Superficiales

- PS: NANO-ÓPTICA/METAL $\Leftrightarrow$ THZ/SEMICONDUCTOR
- RADIACIÓN EM–PS: *SERS*, FLUORESCENCIA, . . .

ACTIVIDAD PRESENTE/FUTURA

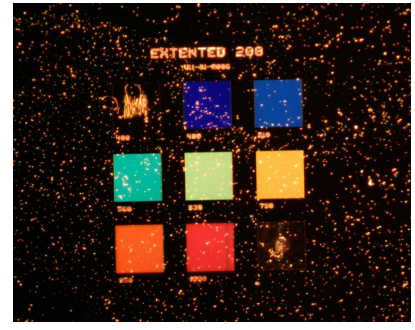
SP Optics

SPP-GAP States



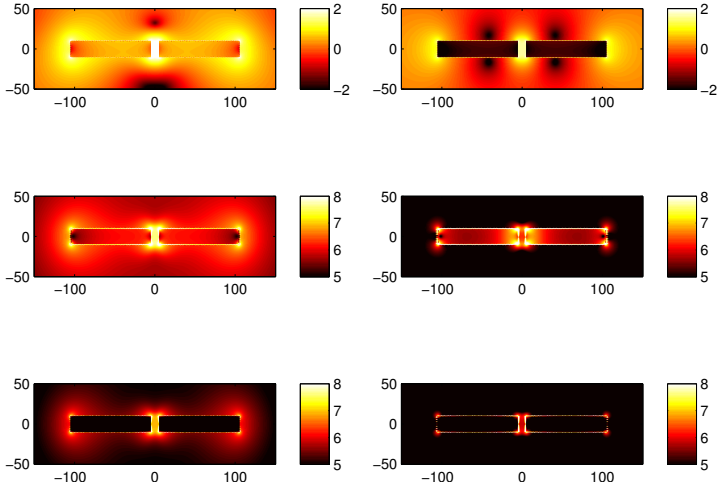
Nanophotonics

SP-Nanowire



SERS, SEF & related

SPR-Nanoantennas



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